

APPLICATION
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TITLE: METHOD AND APPARATUS FOR REDUCING ECHO
AND CROSSTALK IN A COMMUNICATION SYSTEM

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**METHOD AND APPARATUS FOR REDUCING ECHO AND CROSSTALK
IN A COMMUNICATION SYSTEM**

BACKGROUND

[0001] The following disclosure relates to electrical circuits.

[0002] A communication system (e.g., a local area network) allows communication between two or more network devices. FIG. 1 illustrates an example communication system 100 that includes a network device 102 and a network device 104. Network devices 102, 104 include computers, switches, routers, hubs, gateways, and similar devices (e.g., devices having a network interface card in a network). Though two network devices are illustrated in FIG. 1 by way of example, communication system 100 can contain a different number of network devices.

[0003] Referring to FIG. 2, communication between network device 102 and network device 104 can be conventionally achieved using a communication line 106, formed by unshielded twisted pairs (UTP) of wires (or cables), and transceivers 108-122, one transceiver positioned at each end of a UTP. For example, four UTPs 124-130 are provided in communication line 106 between network device 102 and network device 104. Hybrid circuits 132-146 (e.g., transformers) can be used at the ends of each UTP 124-130 to control access to a corresponding communication channel for full-duplex bidirectional operation. The combination of a hybrid circuit and a transceiver forms one

communication channel. Accordingly, FIG. 2 illustrates four channels of communication, each operating in a similar manner. Each UTP 124-130 is connected to a corresponding transceiver through connectors 148-162.

[0004] A common problem associated with a communication system using multiple UTPs and multiple transceivers is noise in the form of interference signals. The interference signals include echo and near-end crosstalk (NEXT). As a result of these interference signals, the performance of transceivers, in particular the receivers, in a communication system is degraded.

[0005] An echo interference signal can be produced by each transmitter contained within the same transceiver as a given receiver. Echo interference signals 302-316 encountered by respective receivers R1-R8 (of transceivers 108-122) are shown in FIG. 3. Echo interference signals 302-316 appear as noise to receivers R1-R8, which are attempting to detect a direct communication signal (e.g., a data symbol) from a transmitter T1-T8 connected at the opposite end of the communication channel. Accordingly, communication signals received by receivers R1-R8 of transceivers 108-122 may experience signal distortion due to echo interference signals 302-316.

[0006] NEXT is an interference signal that results from capacitive coupling of signals from a near-end transmitter to the input of a receiver. For example, NEXT interference signals

402-406 encountered by receiver R1 of transceiver 108 are shown in FIG. 4. NEXT interference signals 402-406 appear as noise at the input of receiver R1, which is attempting to detect a direct communication signal from transmitter T5 of transceiver 116. Each of receivers R1-R8 of transceivers 108-122 may encounter the same effect, and accordingly the communication signals received by receivers R1-R8 may also experience signal distortion due to NEXT interference signals. FIG. 5 shows an example time domain representation of echo and NEXT interference signals encountered by receiver R1 of transceiver 108. Echo and NEXT interference signals caused by a reflection due to impedance mismatch at hybrid circuit 132 and connector 148 are identified as the high voltage responses close to zero time.

SUMMARY

[0007] In general, in one aspect, this specification describes a transceiver. The transceiver includes a receiver to receive an analog communication signal. The analog communication signal contains an interference signal. The transceiver includes a digital compensation circuit to generate a digital replica of the interference signal contained in the analog communication signal, a converter to convert the digital replica of the interference signal into a corresponding analog replica of the interference signal, and a subtraction circuit to subtract the

analog replica of the interference signal from the analog communication signal.

[0008] Particular implementations may include one or more of the following features. The digital compensation circuit can include an echo canceller to generate a digital replica of an echo interference signal in the analog communication signal. The digital compensation circuit can further include a near-end crosstalk (NEXT) canceller to generate a digital replica of a NEXT interference signal in the analog communication signal. The transceiver can further include an analog-to-digital converter (ADC) to sample the analog communication signal having the analog replica subtracted therefrom, and generate a digital signal that is substantially devoid of the interference signal. The transceiver can further include a first-in-first-out (FIFO) buffer to receive the digital signal and store the digital signal on a first-in-first-out basis. The transceiver can further include a feed forward equalizer (FFE) to receive the digital signals from the FIFO buffer, the FFE operable to filter individual digital signals. The FFE can be a least means square (LMS) type adaptive filter. The transceiver can further include a data detector to detect data from the filtered individual digital signals. The data detector can be a Viterbi detector. The data can be a data symbol.

[0009] In general, in another aspect, this specification describes a method for reducing interference signals in an analog communication signal. The method includes receiving an analog communication signal through a receiver. The analog communication signal contains an interference signal. The method further includes generating a digital replica of the interference signal contained in the analog communication signal, converting the digital replica of the interference signal into a corresponding analog replica of the interference signal, and subtracting the analog replica of the interference signal from the analog communication signal to substantially cancel the interference signal from the analog communication signal.

[0010] Particular implementations may include one or more of the following features. The interference signal can be an echo interference signal or a near end crosstalk (NEXT) interference signal. Generating a digital replica of the interference signal can include determining cancellation coefficients that model an impulse response of the interference signal, and multiplying the cancellation coefficients with a communication signal from a transmitter that causes the interference signal. Determining cancellation coefficients can include determining cancellation coefficients using an adaptive filter. The method can further include sampling the analog communication signal having the

analog replica subtracted therefrom with an analog-to-digital converter (ADC) to create a digital communication signal.

Generating a digital replica of the interference signal can include generating a digital replica of a portion of the interference signal. The portion of the interference signal can include high voltage portions of the interference signal.

[0011] In general, in another aspect, this specification describes a network device in a communication system. The network device includes a transceiver operable to receive an analog communication signal containing an interference signal. The transceiver includes a receiver to receive the analog communication signal, a digital compensation circuit to generate a digital replica of the interference signal contained in the analog communication signal, a converter to convert the digital replica of the interference signal into a corresponding analog replica of the interference signal, and a subtraction circuit to subtract the analog replica of the interference signal from the analog communication signal.

[0012] In general, in another aspect, this specification describes a cancellation system for use in a communication system including a communication line. The communication line has a transmitter and a receiver at each end. The cancellation system reduces interference signals in an analog communication signal received by a receiver. The cancellation system includes

an echo canceller associated with a receiver. The echo canceller receives a transmitted signal from a transmitter in a same transceiver as the receiver with which the echo canceller is associated. The echo canceller is operable to generate a digital replica echo interference signal. The cancellation systems further includes a converter to convert the digital replica of the echo interference signal into a corresponding analog replica of the echo interference signal, and a subtracter to subtract the replica echo interference signal from an analog communication signal received by the receiver.

[0013] In general, in another aspect, this specification describes a cancellation system for use in a communication system including a communication line. The communication line has a transmitter and a receiver at each end. The cancellation system reduces interference signals in an analog communication signal received by a receiver. The cancellation system includes a NEXT canceller associated with a receiver. The NEXT canceller receives a transmitted signal from a local transmitter. The NEXT canceller is operable to generate a digital replica NEXT interference signal. The cancellation system further includes a converter to convert the digital replica of the NEXT interference signal into a corresponding analog replica of the NEXT interference signal, and a subtracter to subtract the

replica NEXT interference signal from an analog communication signal received by the receiver.

[0014] At high frequencies, echo and NEXT interference signals become a significant portion of a received communication signal. The systems and techniques described in this specification remove high voltage portions of echo and NEXT interference signals in a received communication signal prior to the received communication signal being sampled by an analog-to-digital converter. Bit resolution of the analog-to-digital converter is therefore preserved. Specifically, for high throughput systems, the effective number of bits (ENOB) is a critical design parameter.

[0015] The details of one or more implementations are set forth in the accompanying drawings and the description below. Other features and advantages will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

[0016] FIG. 1 is a schematic block diagram of a conventional communication system.

[0017] FIG. 2 is a schematic block diagram of a plurality communication channels, each with a transceiver at each end.

[0018] FIG. 3 is a schematic block diagram of a portion of the communication system of FIG. 2 depicting echo interference signals.

[0019] FIG. 4 is a schematic block diagram of a portion of the communication system of FIG. 2 depicting NEXT interference signals.

[0020] FIG. 5 is a graph showing echo and NEXT interference signals of a communication channel.

[0021] FIG. 6 is a schematic block diagram of a communication system.

[0022] FIG. 7 is a schematic block diagram of a plurality communication channels, each with a transceiver at each end.

[0023] FIG. 8 is a schematic block diagram of a transceiver structure.

[0024] FIG. 9 is a schematic block diagram of an echo canceller of FIG. 8.

[0025] FIG. 10 is a schematic block diagram of a NEXT canceller of FIG. 8.

[0026] FIG. 11 is a schematic block diagram of a transceiver structure.

[0027] FIG. 12 is a schematic block diagram of an echo canceller of FIG. 11.

[0028] FIG. 13 illustrates a process for reducing echo and NEXT interference signals in a communication signal.

[0029] Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0030] A communication system 600 incorporating features of the systems and methods for reducing echo and NEXT interference signals is generally shown in FIG. 6. Communication system 600 includes a network device 602 and a network device 604. As discussed above Network devices 602, 604 include computers, switches, routers, hubs, gateways, and similar devices. Two network devices are shown by way of example - communication system 600 can contain a different number of network devices. Network device 602 communicates with network device 604 through a communication line 606.

[0031] Referring to FIG. 7, in one implementation, communication line 606 includes four UTPs 724-730 that are connected to transceivers 708-722 through corresponding connectors 748-762. In one implementation, transceivers 748-762 are IEEE 1000Base-TX compliant. Hybrid circuits 732-746 are used at the ends of each UTP 724-730 to control access to a corresponding communication channel for full-duplex bidirectional operation.

[0032] FIG. 8 shows one implementation of a transceiver structure 800 of transceiver 708. Transceivers 710-722 can

include similar transceiver structures and operate in a similar manner. The transmitter portion 801 of transceiver 708 includes a conventional pulse shaping filter 802 and a digital-to-analog converter (DAC) 804. Pulse shaping filter 802 receives one or more data symbols (Tx1Data) to be transmitted over the first communication channel between transceiver 708 and transceiver 716. Data symbols Tx1Data transmitted by transmitter T11 pass through pulse shaping filter 802 and are converted into analog signals by DAC 804. The analog signals gain access to UTP 724 through hybrid circuit 732.

[0033] The receiver portion 803 of transceiver 708 includes a digital compensation circuit 805, an analog-to-digital converter (ADC) 816, a FIFO 820, a feed forward equalizer (FFE) 822, a data detector 826, and a feedback filter 828. Digital compensation circuit 805 generates a digital compensation signal to substantially cancel echo and/or NEXT interference signals from a received communication signal (received from transmitter T15) appearing at receiver R11. In one implementation, digital compensation circuit 805 includes an echo canceller 806 and a NEXT canceller 808.

[0034] Echo canceller 806 generates a digital replica of the echo interference signal encountered by receiver R11 of transceiver 708. In like manner, NEXT canceller 808 generates a digital replica of the NEXT interference signals encountered by

receiver R11. In one implementation, the digital replica of the echo interference signal is combined with the digital replica of the echo interference signal through combiner 810. The combined digital replica of the echo and NEXT interference signals can be converted into a corresponding analog replica of the echo and NEXT interference signals through digital-to-analog converter (DAC) 812. Signal distortion caused by echo and NEXT interference is cancelled from the received communication signal by subtracter 814 (i.e., subtracting the analog replica of the echo and NEXT interference signals from the received communication signal).

[0035] In one implementation, echo canceller 806 and NEXT canceller 808 receive as inputs a stream of data symbols generated by local transmitters (e.g., transmitters R11-R14). The analog replica echo and NEXT interference signals are subtracted from the received communication signal prior to the received communication signal being sampled by ADC 816. Echo and NEXT interference signals are, therefore, removed from the received communication signal in the analog domain.

[0036] ADC 816 samples the received communication signal, that is substantially devoid of signal distortion caused by echo and NEXT interference signals, in accordance with a sample clock signal 818 and generates digital signals at a suitable frequency, for example, at 833 MHz with an 8 bit resolution.

Sample clock signal 818 can be provided by a timing recovery circuit (not shown). FIFO 820 receives the digital signals and stores them on a first-in-first-out basis. FIFO 820 forwards individual digital signals to FFE 822 which filters the individual digital signals. In one implementation, FFE 822 is a least means squares (LMS) type adaptive filter which performs equalization and precursor inter-symbol interference (ISI) cancellation. Data detector 826 receives the individual filtered signals and, in combination with combiner 824 and feedback filter 828, generates an output signal corresponding to a detected data symbol. Data detector 826 can be a symbol-by-symbol detector or a sequential detector which operates on sequences of signals across all four channels, such as a Viterbi detector.

[0037] FIG. 9 shows an implementation of echo canceller 806. Echo canceller 806 includes a shift register 900, an adaptive cancellation filter 902, and a combiner 904. Shift register 900 receives data symbols Tx1Data. Shift register 900 can have a size (N_e) equal to a length of echo canceller 806. Adaptive cancellation filter 902 produces echo cancellation coefficients that model impulse responses of the echo interference signal encountered by receiver R11. A digital replica of the echo interference signal encountered by receiver R11 is generated by multiplying the echo cancellation coefficients with data symbols

TxlData and summing the results through combiner 904. Adaptive cancellation filter 902 can be implemented as an adaptive transversal filter (ATF) using, for example, the LMS algorithm. The digital replica of the echo interference signal can be sent to combiner 810 and to DAC 812. DAC 812 can be clocked with clock signal 818 to ensure that echo interference signals are properly cancelled out at subtracter 814. Timing delays that may be associated with the generation of the digital replica of the echo interference signal can be compensated for by appropriate time domain manipulations of the digital replica interference signal.

[0038] As discussed above (FIG. 7), communication signals transmitted by the transmitters T11-T18 of transceivers 708-722 may cause NEXT interference signals in communication signals received by the receivers R11-R18 of transceivers 708-722. Referring again to FIG. 7, since each receiver R11-R14 has access to data symbols on the other (e.g., three) channels that may cause the NEXT interference signals, NEXT interference signals can be substantially cancelled.

[0039] FIG. 10 shows an implementation of NEXT canceller 808 that substantially cancels NEXT interference signals caused by transmitters T12-T14 (FIG. 8). Next canceller 808 includes shift registers 1000-1004, NEXT adaptive filters 1006-1010, and combiners 1012-1018. Shift registers 1000-1004 receive data

symbols TxData2, TxData3, and TxData4 from transmitters T2-T4, respectively. Each NEXT adaptive filter 1006-1010 generates NEXT cancellation coefficients that model impulse responses of the NEXT interference signal caused by given transmitters T12-T14, respectively. In one implementation, NEXT adaptive filters 1006-1010 are implemented as ATFs, each using the LMS algorithm. Individual digital replicas of NEXT interference signals caused by transmitters T12-T14 are generated by multiplying the NEXT cancellation coefficients with a respective one of data symbols TxData2, TxData3, and TxData4, and summing the results through combiners 1012-1016. Combiner 1018 sums the individual digital replicas of NEXT interference signals to produce a digital replica of the total NEXT interference signals encountered by receiver R11. In one implementation, the digital replica of the total NEXT interference signals is combined with the digital replica of the echo interference signal by combiner 810 and sent to subtracter 814 through DAC 812. Alternatively, any number of the individual digital replicas of the NEXT interference signals can be sent directly to DAC 812.

[0040] FIG. 11 shows an alternative implementation of a transceiver structure 1100 of transceiver 708. In the implementation shown in FIG. 11, echo canceller 1102 and/or NEXT canceller 1104 removes high voltage responses (e.g., caused by a reflection due to impedance mismatch at hybrid circuit 132 and

connector 148) within a received communication signal before the received communication signal is sampled by ADC 816. The remainder of the echo and NEXT interference signals (contained in the received communication signal) that is not removed by echo canceller 1102 and NEXT canceller 1104, is removed by a conventional echo canceller 1106 and a conventional NEXT canceller 1108 in the digital domain (i.e., after the received communication signal has been sampled by ADC 816).

[0041] FIG. 12 shows an implementation of echo canceller 1102. NEXT canceller 1104 has the same principle operation of echo canceller 1102. Echo canceller 1102 includes a shift register 1200, a programmable delay 1202, an adaptive cancellation filter 1204, and a combiner 1206. Data symbols Tx1Data are passed into shift register 1200 after a pre-determined amount of time. The pre-determined amount of time is adjustable through programmable delay 1202 to ensure that a generated replica echo interference signal arrives substantially coincident with a received echo interference signal at subtracter 1110. Adaptive cancellation filter 1204 produces echo cancellation coefficients that model high voltage impulse responses of the echo interference signal. Adaptive cancellation filter 1204 can be implemented as an adaptive transversal filter (ATF) using, for example, the LMS algorithm. A digital replica of the high voltage echo interference signals encountered by receiver R11 is generated by

multiplying the echo cancellation coefficients with data symbols Tx1Data and summing the results through combiner 1206. The digital replica of the high voltage echo interference signals can be sent to subtracter 1110 through DAC 812.

[0042] FIG. 13 shows a method 1300 for reducing echo and NEXT interference signals in a received communication signal. A communication signal is received by a receiver (step 1302). A digital replica of an interference signal (or a portion thereof) is generated (step 1304). In one implementation, a digital replica of all interference signals encountered by a receiver are generated, including echo and all NEXT interference signals encountered by a receiver. In another implementation, a digital replica of a number of the interference signals less than all of the interference signals can be generated in step 1104. The digital replica of the interference signal(s) are converted into a corresponding analog replica interference signal(s) (step 1306). The analog replica interference signal(s) are subtracted from the received communication signal (step 1308). In one implementation, the analog replica interference signal(s) are subtracted from the received communication signal to substantially remove the interference signal(s) from the received communication signal. After the replica interference signal(s) have been removed from the received communication

signal, the received communication signal is then sampled by an ADC for digital processing (step 1310).

[0043] Various implementations have been described.

Nevertheless, it will be understood that various modifications may be made. For example, instead of in an adaptive manner, the echo cancellers and NEXT cancellers described above can generate corresponding replica interference signals deterministically.

In addition, the number of transmitters and receivers per transceiver can be different. Accordingly, other implementations are within the scope of the following claims.